



Eight computer-controlled Buick LeSabres drive in tight formation down Interstate 15, California

DRIVING AMBITIONS

Motorway pile-ups could become a thing of the past with the arrival of vehicles that can drive themselves, but are we ready to let go of the steering wheel? Mike Bedford sits back and enjoys the ride

The car is an integral part of most of our daily lives, but with problems such as traffic jams, pollution and accidents, it also comes in for plenty of criticism.

Some see the solution as a matter of building more roads or improving public transport, but others are working to combine the best of personal and public transport. If today's research into driverless vehicles comes to fruition we could see less congestion, fewer accidents and lower pollution while still enjoying the convenience of having our own transport to take us from door to door.

Driverless passenger vehicles such as trains and planes bring economic advantages, too. Computers don't need wages, and their hours of work are not restricted by legislation. There are even military benefits, as driverless vehicles could run combat missions in place of humans.

Unfortunately, getting computers to drive cars and pilot aircraft is no mean feat. Controlling a vehicle requires all sorts of skills, such as pattern recognition, that are far from simple for a computer. A person has no difficulty in

recognising that the car in front of them is braking, but programming a computer to do the same is a different matter. What's more, while people are very good at adapting to the unexpected, computers are not.

PILOT SCHEME

Basic forms of automation, such as cruise control in cars and a plane's autopilot, have been around for years, but the crucial difference between this and a fully autonomous vehicle is that there are always manual controls and a human there to take over in case something goes wrong. So how does new technology deal with the unexpected? According to the Federal Highways Administration in the USA, one answer is to move driverless cars in convoys to provide a highly controlled situation with as little unpredictable behaviour as possible.

In 1997, during a demonstration on a section of Interstate 15 near San Diego, California, eight Buick LeSabres travelled at 65mph in a so-called platoon. Each vehicle was just 6.5 metres from its neighbours. At this spacing, a highway could carry 4,300 vehicles per lane every hour compared to 2,000 vehicles driven manually.

Further reductions in the gaps between cars bring other benefits, too. Wind-tunnel tests at the University of Southern California showed that aerodynamic drag would be cut in half if the cars could be driven with a gap of just half a vehicle length between them. This in turn would reduce



fuel consumption by between 20 and 25 per cent, cutting emissions accordingly.

GOING STRAIGHT

Persuading each car to drive in a straight line without wandering into another lane was simple in principle, although it meant embedding 92,000 magnets into a seven-mile stretch of highway for the cars to follow. A greater challenge was to design technology that enabled the cars to drive in close proximity and react safely in the event of a fault.

Here the researchers used two technologies in combination. Forward-looking radar measured the distance to the car ahead, while a radio communication system provided information, updated 50 times a second, on the speed and acceleration of the two adjacent cars in the platoon. This way the cars were able to respond to the behaviour of the cars ahead of them much more rapidly than a human driver ever could. In effect the platoon behaved like a train in which the linkages were electronic rather than mechanical. In fact, with the gaps between cars remaining so constant, onlookers found it hard to believe there was no mechanical coupling joining them together.

Also key to the demonstration was the means by which cars joined and left the platoon. These actions relied on simple extensions to the basic control mechanism. A car wishing to join the platoon would accelerate automatically until it came within the specified distance of the car in front, at which point it would operate as described above. A car leaving the highway would gradually increase the space between it and its neighbours before pulling over into the exit lane, and the rest of the platoon would reform.

Although it didn't form part of the demonstration, the developers also addressed the protocol that would be needed in an operational system before a car would be allowed to enter the automated lane on a highway. Cars would enter through something like a toll booth and, to prevent the drivers of unequipped cars experiencing the white-knuckle ride of a lifetime, only cars that gave the correct response to automatic interrogation would be granted access.

Tricky Manoeuvres

It may be a while before you can travel on a pilotless aircraft or read the newspaper safely at the wheel of your car as you motor along the M1. Even so, systems are already in place or just round the corner to enable commercial airliners and cars to perform some of the trickier manoeuvres automatically.

Everyone knows about the autopilots that keep airliners on course and relieve the pilot of the tedium of long-haul flights. What passengers may not be so familiar with are the advanced systems that are now a part of many passenger aircraft. Here the aim is not to remove the more routine aspects of flying but to carry out some of the most complicated manoeuvres safely and reliably. Most pilots choose to take off and land manually, but many aircraft have systems that can perform these tasks automatically if the pilot chooses, perhaps because of poor visibility.

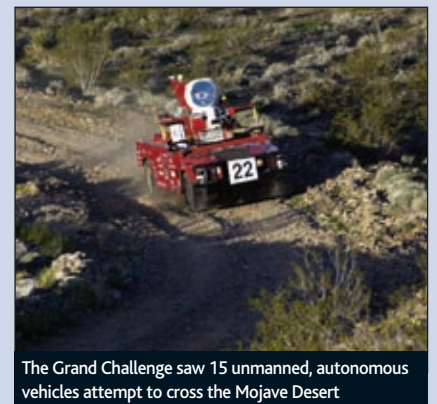
The Grand Challenge

At 6.30am on 13th March 2004 near Barstow, California, the calm of a desert morning was broken by 15 revving engines. The event was the Grand Challenge, a 150-mile race across some of America's most unforgiving terrain. And if that wasn't hard enough, the vehicles had to be fully autonomous; drivers and remote controls were banned.

One million dollars was up for grabs for the first vehicle to arrive in Primm, Nevada. Sadly, just a few hours into the event most teams' hopes of winning the prize were in tatters. After three hours all but four vehicles had broken down, suffered an electronic fault or simply rolled over. Just a few hours later the last remaining vehicle, operated by the Red Team, ground to a halt after only 7.4 miles. It failed to negotiate a hairpin bend and got stuck on an embankment.

Obstacles were not the only challenge, though. Just as important and problematic was the software each vehicle used to navigate from one waypoint to the next using GPS. According to Grand Challenge deputy program manager Tom Strat, "some of the vehicles were able to follow the GPS waypoints very accurately but were not able to sense obstacles ahead. Other vehicles were very good at sensing obstacles, but had difficulty following waypoints or were scared of their own shadow, hallucinating obstacles when they weren't there."

The event's sponsor, America's Defense Advanced Research Program Agency (DARPA), is still keen to award the million-dollar prize and is fully committed to running the Grand Challenge until 2007. Its motivation isn't hard to appreciate. With soldiers on routine reconnaissance missions being killed frequently in Iraq, the US military is eager to do for ground-based vehicles what Global Hawk has achieved in the air. According to the 2001 Floyd D Spence National Defense Authorization Act, "it shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that, by 2015, one-third of the operational ground combat vehicles are unmanned."



The Grand Challenge saw 15 unmanned, autonomous vehicles attempt to cross the Mojave Desert

SAFETY FIRST

Safety is always the main concern for any means of transport, but this is especially true of a system in which people hand over the responsibility of their safety to a computer. Knowing this, the developers took pains to make it fail-safe. Each car communicated with its neighbouring vehicles in the platoon, so if a fault were to develop in

one car, all the others would become aware of the situation within milliseconds. At this point each car would drop back from the car in front and warn its occupants. Furthermore, as each car expects to receive updates from its neighbours 50 times a second, a system failure in any one car would immediately be recognised by the others as no signal would be received. If that car ground to a halt, the cars following could be stopped without the risk of a pile-up, which is all too common when human reaction times come into play.

Today the Federal Highways Administration has little to say on this topic, having cancelled the project in 1998. So what happened to research into driverless cars? The main drawback with this early demonstration was that it required special lanes that would be occupied solely by vehicles operating in platoons. Adding an extra lane to existing highways would have cost a fortune.

The solution would be a system that enables autonomous and driven vehicles to use the same lanes of the same highway at the same time, but here progress is much slower. Needless to say, designing systems that can cope with the vagaries of human drivers is much more of a challenge.

PLANE SAILING

High Altitude Platforms (HAPs) are airborne cellular base stations and broadcast transmitters that provide mobile phone and broadband internet coverage to large, sparsely populated areas. Piloting an HAP in a 5km circle hundreds of times in an eight-hour shift isn't the most exciting job imaginable, so it's not surprising that much of



By 2010, Boeing's unmanned X-45C will be ready for combat missions



In 2001, a US Air Force Global Hawk flew itself non-stop from California to Australia

today's research into civilian Unmanned Aerial Vehicles (UAVs) is concerned with HAPs.

Developers reached a milestone in June with the maiden flight of the world's first liquid hydrogen-powered UAV. AeroVironment's Global Observer prototype aircraft has a 50-foot wingspan and will be able to operate at an altitude of 65,000 feet for over a week. By using just two aircraft in rotation, with one Global Observer replacing the other on station once a week, the company claims that communication systems could be provided at previously unachievable levels of affordability.

Communications isn't the only airborne application that could benefit from automation. Other routine jobs include aerial photography and crop spraying, and there's considerable speculation that cargo planes will soon be autonomous. Some experts predict that this will happen as early as 2010.

The question on everyone's lips, though, is when, if ever, we can expect to board a passenger plane that has no human pilot on board. Neither Boeing nor Airbus had anything to say about research into autonomous passenger airliners. Is that because of commercial sensitivity or the likelihood of public opposition? Or is it simply that there really is no serious work going on in this area?



Two Boeing X-45A unmanned aircraft, under the control of a single pilot-operator, successfully completed the first ever multiple unmanned flight demonstration

MILITARY PRECISION

On 23rd April 2001 a US Air Force Global Hawk made aviation history by flying non-stop from Edwards Air Force Base in California to the Royal Australian Air Force Base in Edinburgh, Australia, with no pilot on board. The only human intervention in this record-breaking 23-hour trip was the single instruction to start the voyage. Manufactured by Northrop Grumman, the Global

Hawk isn't an experimental aircraft but one that is now deployed regularly for surveillance in Iraq and Afghanistan. It recently clocked up 6,500 flying hours, of which no fewer than 4,000 were in combat missions.

According to George Guerra, director of Northrop Grumman's Air Force Global Hawk programme, this milestone is proof of the aircraft's reliability and value to the US military. "Early on, the Air Force placed a great deal of confidence in Global Hawk by pressing it into service supporting combat operations well ahead of schedule. Since its debut in [military service], the system has provided unprecedented support to our fighting forces on the ground, at sea and in the air."

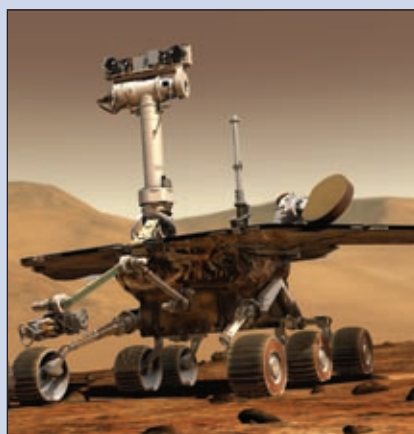
Supporting military operations with unmanned reconnaissance is one thing, but unleashing UAVs with an arsenal of weapons on board is considerably more sinister. Yet progress has been rapid here, too, and with good reason. Military UAVs provide all the benefits of civilian UAVs – no pilots to pay and no possibility of human error – and more. Military pilots are trained to cope with high G-forces, but there are limits to what the human body can withstand. UAVs suffer no such limitations, which means they can achieve unprecedented levels of performance.

Boeing's X-45C is a remarkable aircraft that looks more like a futuristic shuttle from a science-fiction movie. Its delta-shaped wings are just 49 feet across and the plane is just 39 feet long by four feet thick, but it will be able to carry a payload of 4,500 pounds in its two weapons bays and fly at Mach 0.85 when it takes to the skies in 2007. In tests its autonomous predecessor, the X-45A, has dropped

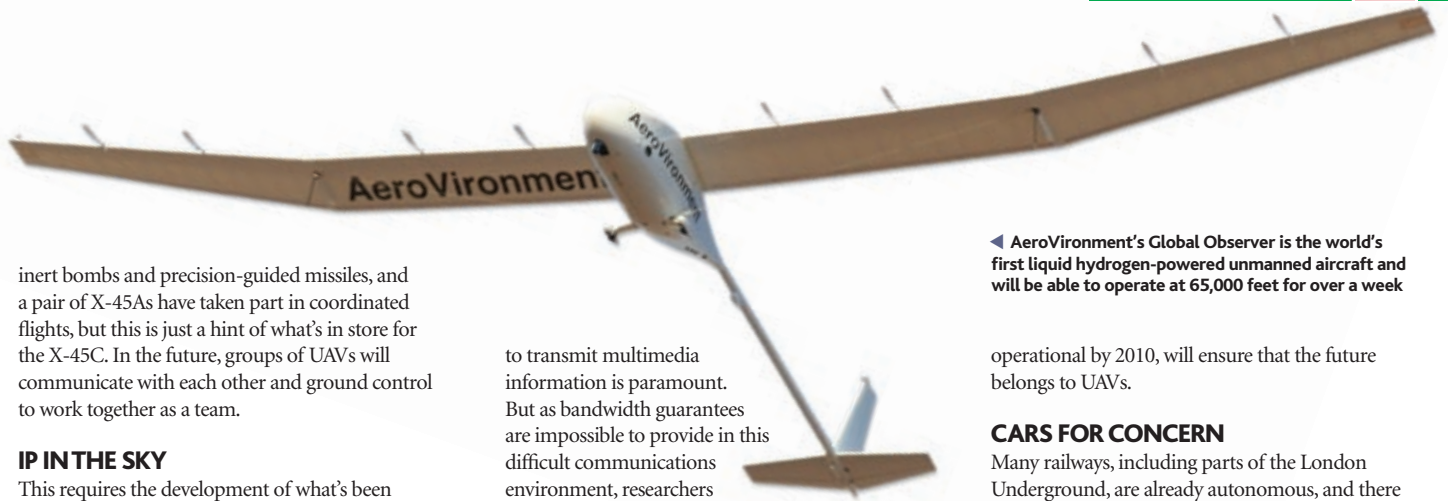
Is there life on Mars?

Despite being designed to operate for just three months, Martian rovers Spirit and Opportunity are still alive and well 18 months after they were deposited by a NASA spacecraft. Their task is to shed new light on how Mars was formed. Rather than being controlled from the Earth, these specialised vehicles drive themselves from A to B, working out their own path and avoiding obstacles en route.

Automating vehicles bound for Mars isn't just a matter of improving efficiency or lowering cost, however; there is simply no other way. Any attempt to drive the rovers remotely from Earth would be scuppered by the fact that radio waves travel at around 300,000km per second. Although this may seem incredibly fast, Mars is sufficiently far away that a radio signal from the Earth would take a quarter of an hour to arrive.



The Martian rovers needed to be autonomous, as the time it takes a radio signal to travel between Mars and Earth makes remote-controlled movement impossible



inert bombs and precision-guided missiles, and a pair of X-45As have taken part in coordinated flights, but this is just a hint of what's in store for the X-45C. In the future, groups of UAVs will communicate with each other and ground control to work together as a team.

IP IN THE SKY

This requires the development of what's been referred to as an 'internet in the sky'. This is no simple feat. The first difficulty is finding a means for vast arrays of agents (mainly but not entirely autonomous vehicles) – including ground-based vehicles travelling at modest speeds and UAVs travelling at hundreds of kilometres per hour – to communicate with each other.

"The traditional mobile IP approach will not scale up to such a large number of mobile agents moving at such high speeds," said Mario Gerla, professor of computer science at the University of California in Los Angeles. To meet this challenge, the researchers are developing an addressing system that takes into account the fact that agents tend to move in groups and will, therefore, include the name of its group in each agent's address.

As some vehicles will be used for information gathering as well as offensive action, the ability

to transmit multimedia information is paramount. But as bandwidth guarantees are impossible to provide in this difficult communications environment, researchers have replaced the concept of guaranteed quality of service with something they call an 'adaptively renegotiable' quality of service.

To achieve this, new video-encoding schemes are being developed that make optimum use of the available bandwidth. Finally, the network must be able to adjust itself dynamically to cope with faults caused by equipment failure or enemy actions. "If one plane goes down, we don't want to lose the whole network," Gerla said.

Despite the engineering hurdles that must still be overcome, the X-45C's prospects look good. Industry experts believe that the F-35 Joint Strike Fighter, which is currently under development by Boeing and Lockheed Martin for deployment by the US Air Force, Navy and Marine Corps and the UK's Royal Navy, will be the last ever to require a pilot. The X-45C, scheduled to become fully

◀ AeroVironment's Global Observer is the world's first liquid hydrogen-powered unmanned aircraft and will be able to operate at 65,000 feet for over a week

operational by 2010, will ensure that the future belongs to UAVs.

CARS FOR CONCERN

Many railways, including parts of the London Underground, are already autonomous, and there seems to be little doubt that passenger aircraft may soon follow, with driverless cars not too far behind. That isn't to say that their introduction will be straightforward, though.

The scene is already set for some fascinating debates. In eliminating the possibility of human error driverless vehicles should be safer, but what about the possibility of catastrophic accidents caused by hardware failure or software bugs? With global warming increasingly on the political agenda, the improved fuel efficiency of autonomous vehicles will attract interest in many quarters. This is unlikely to satisfy motoring organisations, trade unions and those with strong views on personal freedom, though, all of whom have reasons to favour the status quo. With all these competing requirements and aspirations, it looks as though there could be interesting times ahead. **CS**

Public Acceptance

When it opened in 1968, London Underground's Victoria Line was the world's first fully automated passenger rail system. Controlling a train autonomously isn't as difficult as making cars and aircraft operate without human intervention, but it raises some interesting questions. Even Victoria Line trains have a driver sitting in the cab, but why? Is it purely because the public likes to see someone in control? Is it even possible for the driver to take over in the event of an emergency? We wondered whether the Underground has any plans to take that final step in eliminating the human element entirely, so we spoke to Transport for London's Peter MacLennan.

Although there may be elements of public acceptance and union pressure, MacLennan explained that the driver is there to control the trains in areas such as depots and sidings where Automatic Train Operation (ATO) can't be used. ATO performs one simple but highly effective task: to drive a train from one station to the next in the most efficient manner. It can't judge whether it's safe to close the train doors and proceed to the next station, though, so the driver is responsible for closing the doors and engaging the automatic system. In response to my query about whether the driver can take over at any time, we got a reassuring yes.

But what about the future? According to MacLennan, after the Central Line went automatic in 2002 it achieved a 15 per cent improvement in journey times. It's rather

surprising, therefore, that although both the Jubilee and the Northern Lines are equipped for ATO, there are no plans at the moment to extend the system to these lines.

When asked about plans to introduce services with no driver at all, MacLennan said: "There are no plans at this time, although London Underground does keep new developments under review." This isn't a universal philosophy, though. Rail systems from Singapore to Vancouver, and even London's Docklands Light Railway, employ automatic train operation in which humans normally intervene only from a central control room rather than from the train.

Perhaps the biggest questions of public acceptance relate to driverless cars. There are a range of legal issues. For example, if your autonomous car breaks the speed limit or is involved in an accident, who is responsible?

Another serious obstacle is that many people actually enjoy driving. The fact that people like to be in control is evident by the fact that decades after automatic transmission became available most cars in the UK still have a manual gear stick. Manufacturers would face a long struggle if they were to attempt to overcome a century of tradition by removing their customers from the driving seat.



Trains on London Underground's Victoria Line have been driving from platform to platform by themselves for 37 years